How do different management histories influence a soil's phosphorous budget?

By Kalei'ilima Holt holt0711@umn.edu
Mentors: Kyungsoo Yoo and Brent Dalzell
Department of Soil, Water, and Climate

Abstract

Today's growing global population and climate changes point to the inevitable need for sustainable intensification of agriculture. As a result, it is important to better understand how agricultural activities affect elemental budgets in soils, especially those of inorganic nutrients including the increasingly scarce phosphorous (P). Little research has been done to characterize long-term soil P dynamics within a broader context of soil development. This study used the geochemical normalization method to assess long-term losses or gains of P via chemical weathering vs. agricultural activities. The data show that P is depleted in soils relative to parent material in grassland systems, while in the agriculturally managed systems the degrees of the depletions are substantially less. This suggests that fertilizer inputs of P have replenished some of the weathering losses of these elements that had occurred before agricultural management was in place. The data also show significant impacts of agricultural erosion on the P elemental budget, which results in greater topographic variation in soil P in agricultural landscapes than in grasslands. These findings can be used to inform sustainable management of a soil's elemental composition, especially that of residual P in the context of natural P leaching and declining mineral P resources.

Background

Soil nutrient budgets are determined by the balance of nutrient inputs and outputs. In an agricultural context, the inputs refer to fertilizer, soil amendments, and pesticides, while the outputs include harvesting, leaching, and erosion. These fluxes contrast to biological recycling of nutrients and long-term nutrient losses due to chemical weathering in pre-agricultural natural soils. Little effort has been made to employ a soil formation conceptual framework to quantify the long-term accumulations of P in agricultural soils following conversion from natural ecosystems. This project quantified agricultural accumulations of P since the beginning of cultivation and compared the accumulations to the losses in undisturbed natural soils. Row-crop agricultural sites were compared with adjacent prairie sites.

Objective: To better understand how the agricultural practices of applying fertilizer and amendments to soils re-shape the elemental composition and storage in soils by comparing soils under agriculture and natural prairie.

Study Area

The cropland and grassland sites are located in western Fillmore county in southeast Minnesota. Soils in this region are typically Mollisols and Alfisols that are well-drained with moderate to good development. Soils in this part of the county are sandy loess with gradual relief over dense pre-Illinoian till.

Soil Sampling

Samples for this study were selected from an existing sample archive for southern Minnesota. Archive sample points were selected to represent the range of terrain attributes (slope, contributing area, curvature) at a site. Soil pits were used to sample the upper 50 cm of the soil profile at 5-10 cm intervals, and deeper soils were sampled with a multi-stage core sampler in 25 cm intervals down to 150 cm, providing an opportunity to characterize surface soils and deeper parent material. The subset of samples selected for this study are from six sites that represent a contrasting range of management and erosion history. Samples were composited so that six samples represented the 150 cm soil depth at each site (0-10 cm, 10-20 cm, 20-30 cm, 30-50 cm, 50-100 cm, 125-150 cm).

Site	Type	Erosion status
WP D4	Perennial grassland	Steady
WP H8	Perennial grassland	Depositional
CFE H8	Row crop cultivated	Steady
CFE A1	Row crop cultivated	Depositional
CFE E5	Row crop cultivated	Eroding
CFE J10	Row crop cultivated	Eroding

Methods

Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) & Mass Spectrometry (ICP-MS)

ICP-OES and ICP-MS were performed to determine total elemental composition of the samples. Prior to analysis, samples were ground to fine silt size (<120 microns) and acid dissolved using lithium metaborate fusion.

Lithium Metaborate fusion: For each sample, approximately 0.15g of soil was mixed with 0.75g of LiBO2 so as to ensure proper fusion. This mixture was transferred to a graphite crucible that was then placed in a furnace at 1000-1050 degrees C for 10-12 min. Crucibles were removed at 8 min. to mix the liquid and pick up stray molten particles along the sides and then replaced into the furnace until the temperature returned to 1000 deg. C. The crucibles were then removed, swirled, and decanted into polypropylene bottles containing 61.50g of 1 N HCL solution. Bottles were capped and shaken for ~20 min. on a wrist action shaker.

ICP-OES: To analyze for major oxide elements, the fusion solution was diluted 100 fold with Yttrium as an internal standard element. These were then analyzed on a Thermo Scientific iCAP 6500 duo optical emission spectrometer fitted with a simultaneous charge induction detector, which measures elemental emissions using the most appropriate wavelength that is determined by the estimated composition, need for sensitivity, and the avoidance of element spectral overlaps. For each sample, standard, and blank, the analysis is replicated five times and the mean and standard deviation is determined for each selected element.

ICP-MS: To analyze for trace elements, fusion solutions were analyzed on a Thermo Scientific Xseries2 ICP-MS fitted with a hexapole collision/reaction cell. Elements lighter than mass 39 are analyzed at standard mass resolution with no reactive/collision gasses used. Those greater than/equal to 39 are analyzed at standard mass resolution using Helium/ Hydrogen collision reaction mode with kinetic energy discrimination. All elements use five replicates to determine the mean and standard deviation

^{137}Cs:

Radioactive ^{137}Cs was measured for the soil sample archive from which the subsamples were selected as a means of tracking soil movement over the past 50 years. Landscapes were "labeled" with ^{137}Cs as a result of above ground nuclear weapon testing in the 1950s and 1960s (^{137}Cs does not occur naturally in soils.) Since this element binds tightly to soil particles, ^{137}Cs can serve as an effective tracer for soil movement on decadal time scales. A ^{137}Cs conversion model was used to determine soil erosion rates at all sites.

Calculating elemental fluxes:

As required by the geochemical mass balance method, Zirconium (Zr) was used as a reference material to which losses and gains of other elements are compared because it is conservative to dissolution and leaching. Using the Zr data from the ICP-MS, the fractional mass change (T) of P at each horizon (w) relative to its parent material (p) was calculated using the equation:

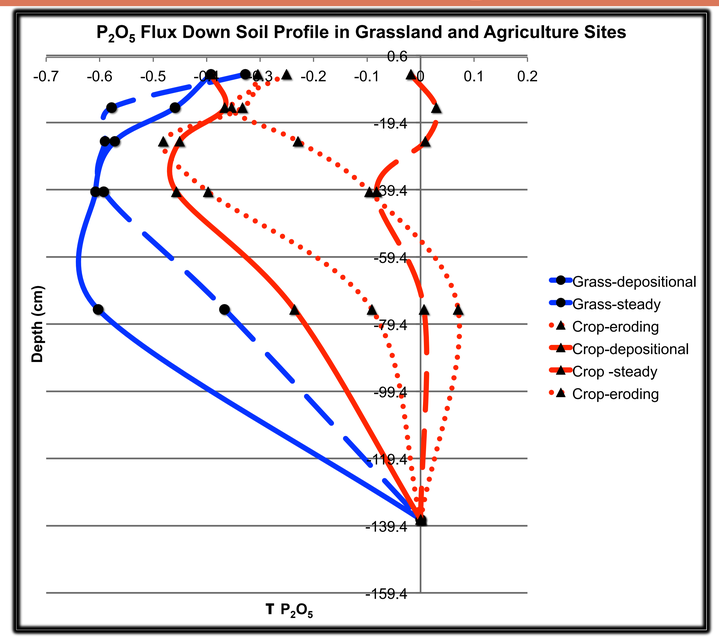
$$T_{j,w}=(C_{j,w}C_{i,p}/C_{j,p}C_{i,w})-1$$

Where j is an element of interest (P in this case) and i is an immobile element, Zr in this case. Positive values of T indicate mass gains or enrichment of P relative to the parent material, and negative values indicate mass loss or depletion of P relative to the parent material. T is a ratio and is unit less.

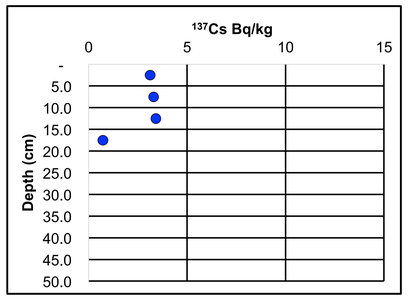
Results & Discussion

P in grassland sites: In both sites, P is depleted at all depths with respect to the parent material. Greatest areas of P depletion are between 20 and 100 cm, suggesting that this is the zone of most active plant uptake. Slightly greater amounts of P in surface soils suggest plant input of P from decomposing biomass. The fact that there are no P values greater than 1 indicates that the system is losing P over time.

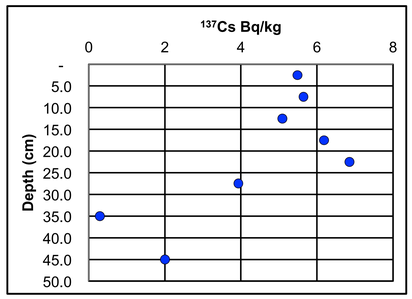
P in cropland sites: With the exception of the depositional site, P is depleted at all depths with respect to parent material in all cropland sites. These sites are not as depleted as the grassland sites, reflecting the P application history through fertilizer inputs. In the eroding cropland sites, significant P depletion begins at shallower depths relative to the grassland sites and other cropland sites (except for the depositional cropland site), suggesting that as surface soil and soil P is lost to erosion, the soil surface is lowering over time, which results in more "fresh" parent material P being closer to the surface. This suggests that soil and soil P is being eroded at a faster rate than the parent material can supply to the shallower depths through weathering.



T P_2O_5 Depth Profile at Grassland and Cropland Sites: For each site, P concentrations relative to Zr concentrations down to a 150 cm depth



^{137}Cs depth profile at CFE-E5 (Crop-eroding): ^{137}Cs concentrations down to a 50 cm depth at site CFE-E5



^{137}Cs depth profile at CFE-A1(Crop-depositional): ^{137}Cs concentrations down to a 50 cm depth at site CFE-A1

P Movement Traced by ^{137}Cs: The depositional cropland site is P-enriched relative to the other cropland and grassland sites. This suggests that P is carried with soil deposited to this site via erosion, creating the relatively P-enriched soil. Therefore, erosion could be seen as an important mechanism of P redistribution around a landscape. This is supported by the difference between the ^{137}Cs depth profiles of an eroded cropland site (CFE-E5 above) and a depositional cropland site (CFE A1 above). Since ^{137}Cs tightly binds to soil particles, the above ^{137}Cs graphs show (with a lower concentration of ^{137}Cs in the eroding site and a relatively higher concentration of ^{137}Cs in the depositional site) evidence of soil movement from the eroding cropland site to the depositional cropland site.

Conclusions

With the exception of the depositional cropland site, P is depleted in all sites relative to the parent material. However, the extent of depletion is less in the cropland sites, reflecting a history of fertilizer P inputs that replenished some of the weathering loss of P occurring before the land was cultivated. The shallower depth of significant P depletion at the eroding cropland sites suggest that erosion and distribution of soil P is occurring at a faster rate than the parent material can replace through weathering. This is supported by the relatively P-enriched depositional cropland site and the difference in ^{137}Cs concentration between the two landscape positions. As a result, erosion could be considered an important mechanism of P movement in a landscape.

On-going work: Analyses to determine soil pH, exchangeable cation concentrations, and concentrations of other elements have also been completed. Surface area of soil particles at each site is currently being determined. These data, along with the ^{137}Cs data, will be used in on-going work to better understand how management affects the elemental budget of soils.

Acknowledgements: Special thanks to Rick Knurr (Senior Scientist at the Department of Earth Sciences Geochemical Lab) and Adrian Wackett (Junior Scientist at the Department of Soil, Water, & Climate) for their help. Samples were run at the Department of Earth Sciences Geochemical Lab and the Research Analytical Laboratory.